LABORATORY FOR

ATMOSPHERES

Section 4

4. Major Activities

4.1 The Context of Laboratory Research

The research activities of the Laboratory are congruent with the science priorities at NASA Headquarters. Thus, our activities must be seen in the context of NASA programs and goals.

There are four core program areas (or enterprises) in NASA: 1) MTPE, which looks toward our planet to better understand the interactions of its system components and develop a capability to predict its future evolution; 2) Space Science, which explores our star system and beyond to better understand the universe and the origin of life; 3) Human Exploration and Development of Space, which expands the human presence beyond the Earth; and 4) Aeronautics, which develops and transfers innovative flight technologies. The Laboratory's activities are focused mainly on MTPE, with a substantial component directed to Space Science.

Atmospheric Science Activities

MTPE is NASA's contribution to the U.S. Global Change Program. An ambitious program designed to investigate the Earth as an integrated system, MTPE is a program with great scientific challenges and important practical applications. The mission has identified five areas of research as having high priority. From the 1996 "Mission to Planet Earth Strategic Enterprise Plan 1996-2002," these are:

- Atmospheric Ozone

To detect and identify causes of atmospheric ozone changes and evaluate consequences.

- Seasonal-to-Interannual Climate Prediction

To provide global observations and gain scientific understanding to improve forecasts of the timing and geographic extent of transient climate anomalies.

- Long-Term Climate Variability

To provide global observations and gain scientific understanding of the mechanisms and factors which determine long-term climate variations and trends.

- Land Cover Change and Global Productivity

To report and understand the trends and patterns of change in regional land-cover, biodiversity, and global primary production.

- Natural Hazards

To apply MTPE remote sensing science and technologies to disaster characterization and risk reduction from earthquakes, wildfires, volcanoes, floods, and droughts.

The Laboratory atmospheric science activities are outlined in graphic form in Figure 1a with the MTPE science priorities identified at the center. The activities are divided into three groups: measurements and data products, data analysis, and modeling. These groups cut across the MTPE science priorities as well as the organizational structure of the Laboratory. They also correspond to the process of asking the scientific question, identifying the geophysical variable needed to answer it, conceiving the best instrument to measure it, analyzing the data, modeling the results, and asking the next question.

The group activities can be summarized as follows:

Measurements and Data Products

Measurements

The Laboratory has a number of experimental activities distributed throughout the branches. They include:

1) Measurements from Space Laboratory scientists have pioneered the development of space-based ozone measurements since the 60's. This effort involves an active experimental program of measurements from Solar Backscatter Ultraviolet (SBUV) and TOMS, coupled with state of the art UV calibration studies and algorithm development. The resulting 16-year record of TOMS total ozone has played an essential role in understanding the evolution of stratospheric ozone and its trends.

2) Measurements from Ground Based and Aircraft Campaigns

The ER-2 Doppler radar, various ground based and airborne Lidars, and radiometers are conceived to meet numerous objectives: to develop remote sensing capabilities for spaceborne platforms; to help the design and validation of retrieval algorithms; to study cloud properties and the interaction of clouds with aerosol particles and their combined climatic impact; and to measure ozone and trace gases relevant to the chemistry and photochemistry of ozone.

Data Products

The Production of high quality data sets is an important function of the Laboratory for its internal research and for use by the scientific community at large. TIROS Operational Vertical Sounder (TOVS) multiyear temperature and water vapor profiles will contribute to the identification and study of atmospheric properties and changes.

The DAO meteorological reanalysis has produced a multiyear gridded global atmospheric data set for use in climate research, including tropospheric chemistry applications. These data have been widely distributed and have contributed to the improvement of the Goddard EOS (GEOS) General Circulation Model (GCM) and to the understanding of atmospheric behavior. The DAO has the responsibility of incorporating into the analysis the new data types which will be available from MTPE space platforms. The large data volumes associated with MTPE observations require new methodologies for the assimilation of the data.

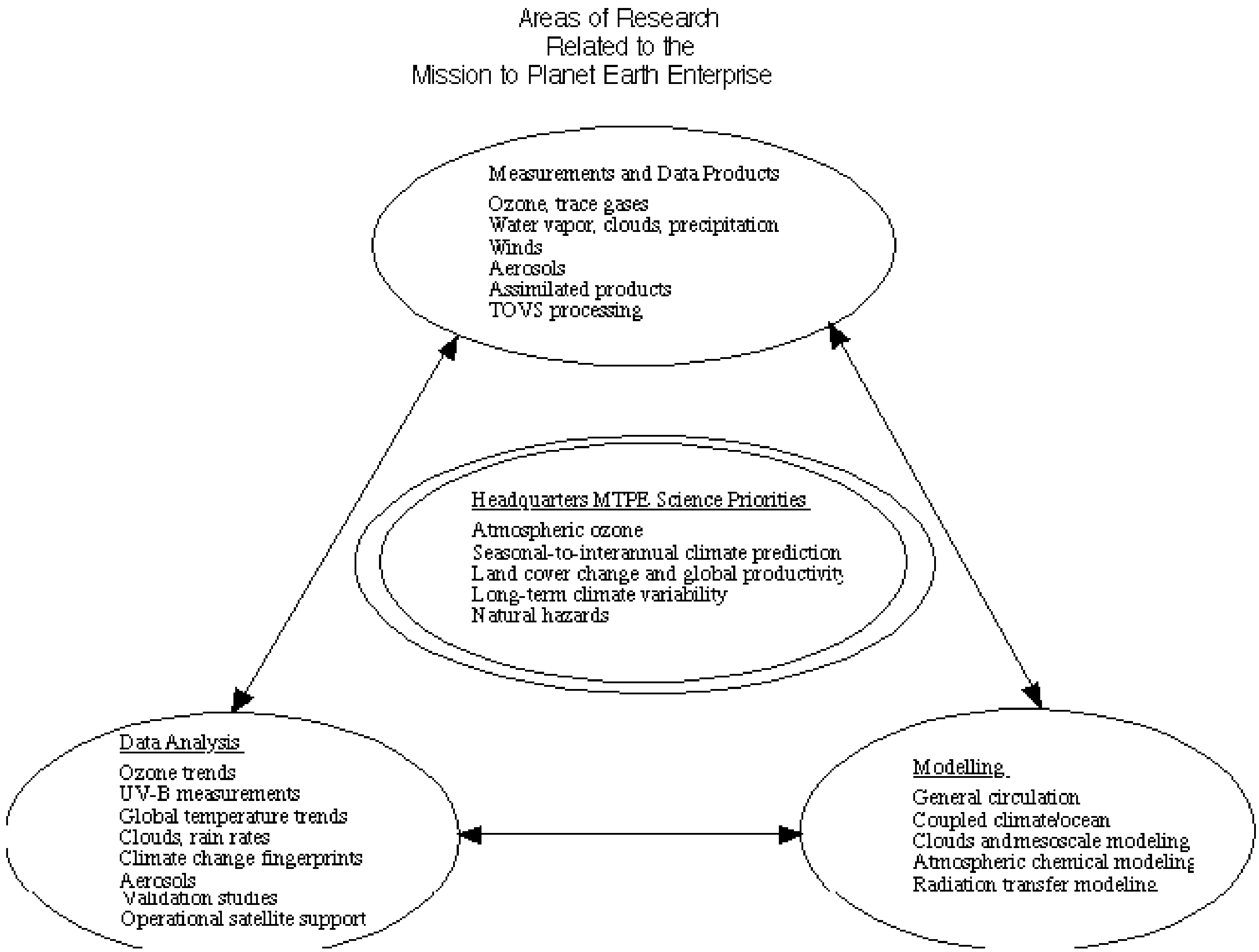

Figure 1a

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Data Analysis

In all research areas substantial efforts are underway in data analysis. The main areas are:

1) Climate Analysis

Advanced analysis techniques are used to identify natural variability on seasonal, inter-annual, and inter-decadal time scales and to isolate it from the anthropogenic signal. The analysis is carried out on a variety of data sets, from satellites, ocean arrays, ground based operational stations, aircraft and other campaigns, validation networks, and data sets from the DAO, the European Center for Medium-Range Weather Forecasting (ECMWF), National Center for Environmental Prediction (NCEP) and other sources.

2) Ozone Trends

Extensive analysis of SBUV, TOMS, aircraft and ground based data on ozone and other trace gases has taken place to identify and explain processes of ozone destruction. Substantial efforts are dedicated to the accuracy of TOMS data, an essential component of ozone trends determination.

3) Aerosols/Cloud Climate Interactions

Extensive studies are underway on the optical properties of aerosols and their effectiveness as condensation nuclei. A variety of data from satellite and experimental campaigns are analyzed to assess the direct and indirect effects of aerosols on climate.

4) Water Vapor and Clouds

Multisensor observations have been utilized to study moisture and water droplet distributions. Analysis of aircraft data shows the potential for contrail cirrus as an anthropogenic factor in climate change. Studies are underway to determine the overall effect of aircraft generated cirrus on climate.

5) Rain Measurements from Space

Laboratory scientists have been involved in algorithm development for measurement of rain rates from space, through the analysis of satellite data, radar and ground based information. This analysis is essential for gaining a better understanding of the hydrologic cycle.

Modeling Studies

The overall goal of the MTPE Program is to determine the causes and the extent of environmental change. A key part of this effort is the development of integrated models which use observations from EOS instruments as well as from standard sources. The ultimate goal is for these models to have predictive capabilities.

Atmospheric models are being developed and used in the following areas:

1) Regional/Cloud Scale Processes

Two- and three-dimensional cloud and regional scale models are used to study classical meteorological problems such as convective systems in the tropics and in mid-latitudes, transport of aerosols and trace gases, stratospheric-tropospheric exchange, air-sea interaction and its cloud-climate feedback. Cloud models are an intrinsic part of the development of retrieval algorithms designed to make maximum use of data that will be produced by the forthcoming TRMM mission. Regional models are also used to develop and test parameterization schemes to be utilized in GCM's.

2) Climate Variability

GCMs are an essential tool to study seasonal, inter-annual, and inter-decadal time scales and to isolate natural variability from the anthropogenic global change signal. In collaboration with the Laboratory for Hydrospheric Processes, substantial efforts are devoted to El Niño Southern Oscillation (ENSO) with the ultimate goal of assessing the role of satellite data on our ability to study and predict the phenomenon. Particular attention is devoted to the development of parameterization codes for radiation and moisture processes which play an essential role in climate sensitivities to cloud microphysics, water vapor, and other trace gases, and in the global water and energy cycles.

3) Trace Gas Modeling

Two- and three-dimensional global models and chemical trajectory models have been developed to interpret the data from various sources including satellites, aircraft, sondes, and ground based stations. They are used to simulate natural and man-made influences on ozone, to study atmospheric motions and transport of trace gases and ultimately to predict quantitative changes in the chemical composition of the atmosphere.

Thus, the activities of the Laboratory relate strongly to the atmospheric ozone, seasonal-to-interannual climate prediction, and long-term variability science priorities of MTPE, and have some connections with the land cover change and global productivity and natural hazards.

Space Science Activities

The Space Science program area seeks to explore and understand the sun, the solar system, the galaxies, and the universe for the benefit of humanity. The programs in the Office of Space

Science are centered around four themes corresponding to fundamental questions.

From the 1995-2000 Strategic Plan "Space Science for the 21st Century" they are:

- The Galaxy and the Universe

What is the Universe? How did it come into being? How does it work? What is its ultimate fate?

- The Connection between the Sun, Earth, and Heliosphere

How does the Sun influence the Earth and the rest of the solar system? What causes solar variability?

- The Origin and Evolution of Planetary Systems

What was the origin of the Sun, the Earth, and the planets, and how did they evolve? Are there worlds around other stars? What are the ultimate fates of planetary systems?

- The Origin and Distribution of Life in the Universe

How did life on Earth arise? Did life arise elsewhere in the universe?

The activities in the Laboratory relate primarily to the second and third theme and are outlined schematically in Figure 1b. The Laboratory has a long history of theoretical and experimental research on the atmosphere of the Earth, beyond the stratosphere, and of other planets. Ion and neutral composition, neutral temperature and wind, and electron temperature and density measurements have been made by Laboratory instruments on the Atmosphere Explorers, Dynamics Explorer, Pioneer Venus Orbiter, and the Galileo missions.

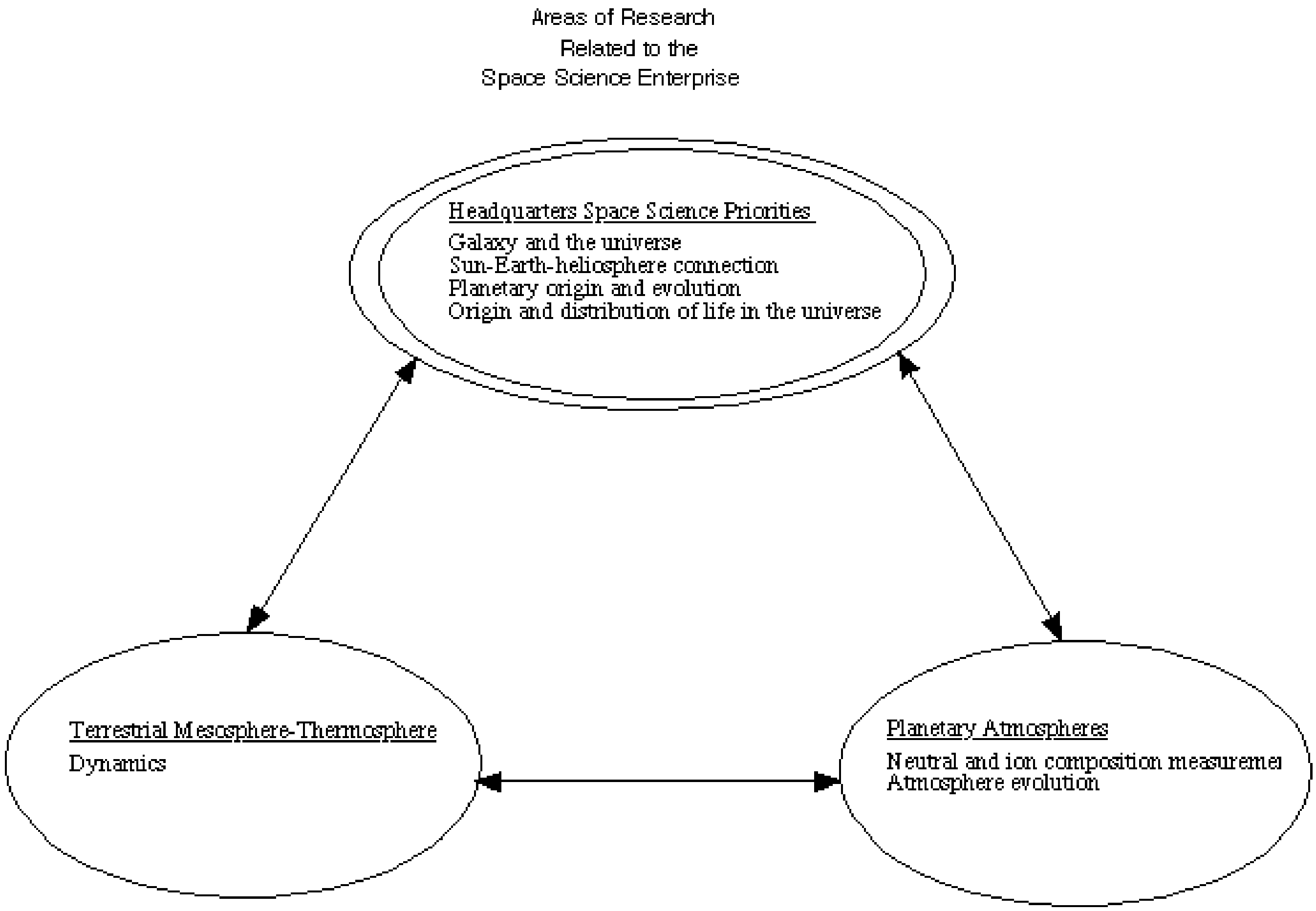

Figure 1b

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Ongoing experimental work includes the Gas Chromatograph Mass Spectrometer (GCMS) to measure the chemical composition of gases and aerosols in the atmosphere of Titan, and the Ion and Neutral Mass Spectrometer (INMS) to measure the chemical composition of positive and negative ions and neutrals in the inner magnetosphere of Saturn and in the vicinity of the icy satellites. Work has just started on a Neutral Mass Spectrometer to measure the neutral atmosphere of Mars, to be flown on a joint mission with Japan.

Major activities in the Laboratory are outlined in this section. Highlights for calendar year 1996 are described in Section 5, which has some overlap with Section 4.

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4.2 Measurements and Data Products

Data Assimilation

The core activities of the DAO are focused on meteorological research, development, and applications of the GEOS Data Assimilation System (DAS). The GEOS DAS is designed to produce research-quality data sets for the MTPE Enterprise. These data sets are derived from diverse sources, are checked for physical and dynamical consistency, and go through a rigorous quality control process. Continuous near real-time production for EOS will start with the launch of the first EOS platform (AM-1). Data sets produced prior to AM-1 will also be an important part of the development effort. The data products of the DAO complement and supplement the EOS observations by providing estimates of unobserved quantities and advanced quality control.

The GEOS-1 DAS is the baseline for later versions of the data assimilation system. It is described in [1]. The GEOS-1 DAS has been used to produce a meteorological data set covering the period from 1980-1993. Other configurations of GEOS-1 DAS are being used to produce stratospheric data sets and forecasts providing real time support for aircraft missions to study ozone chemistry. The GEOS-1 DAS has been used in a wide variety of applications [2], including tropospheric and stratospheric chemistry, interannual variability of climate dynamics, and regional flood and drought cycles. A copy of the GEOS-1 DAS data sets and the DAO tracer transport model has been transferred to Lawrence Livermore National Laboratory for use in atmospheric chemistry assessments of aircraft emissions.

The current version of the DAS is GEOS-2. Its characteristics are highlighted in the major accomplishments section. GEOS-3 DAS will be the operational system for the 1998 launch of the EOS AM-1 platform. Recently, parameterizations for land surface [3] and cloud water [4] were incorporated into the GEOS-2 GCM. These developments provide enhanced surface and lower atmospheric capabilities for the AM-1 platform. Further development of the Physical-space Statistical Analysis System (PSAS), adaptive representation of error covariances, and more sophisticated quality control will provide the basis of the analysis system for GEOS-3. Recent prototypes of marine surface wind and precipitation assimilation techniques show positive impact on the representation of the atmosphere's general circulation by the GEOS DAS. Assimilation of these fundamental climate system quantities will provide significant improvements in the GEOS-3 system. The GEOS-3 DAS is described in the DAO Algorithm Theoretical Basis Document which is available from the DAO at http://dao.gsfc.nasa.gov/subpages/atbd.html. Much of the framework for the GEOS-3 analysis development is given in [5].

1. "An Assimilated Data set for Earth Science Applications," S. D. Schubert, R. B. Rood, J. W. Pfaendtner, *Bull. Amer. Meteor. Soc.*, **74**, 2331-2342, 1993.

2. NASA Technical Memorandum #104606, R. Rood and S. Schubert, **7**, 1995.

3. "Modeling the Land Surface Boundary in Climate Models as a Composite of Independent Vegetation Stands," R. Koster, D. Randal, and M. J. Suarez, *J. Geophys. Res.*, **97**, D3, 2697-2715, 1992.

4. "A Prognostic Cloud Water Parameterization for Global Climate Models," A. D. DelGenio, M.-S. Yao, W. Kovari, and K. K.-W. Lo, *J. Clim.*, **9**, 270-304, 1996.

5. "An Introduction to Estimation Theory," S. E. Cohn, to appear *J. Meteor. Soc.*, Japan, 1997.

Data Sets for Climate Analysis

- TIROS Operational Vertical Sounder (TOVS) Pathfinder

The Pathfinder Projects are joint NOAA/NASA efforts to produce multiyear climate data sets using observations from operational satellites. These include TOVS which is comprised of three atmospheric sounding instruments, the High Resolution Infrared Sounder-2 (HIRS-2), the Microwave Sounding Unit (MSU), and the Special Sensor Unit (SSU) which have flown on the NOAA Operational Polar Orbiting Satellite since 1979. An algorithm developed in the Laboratory to infer temperature and other surface and atmospheric parameters from TOVS observations is being used to reprocess TOVS data from 1979 to 1995. The data are used to study global and regional natural variability and trends between surface and atmospheric anomalies.

Trace Gas Measurements

The Clean Air Act Amendment of 1977 has assigned NASA and NOAA major responsibilities for studying the ozone layer. In the 60's and 70's Laboratory scientists pioneered the development of a space-based ozone measurement system. This group plays a major role in the measurement and modeling of atmospheric trace gases in the middle and upper stratosphere and actively participates in the World Meteorological Organization (WMO) and NASA sponsored assessments of the depletion of the ozone layer. The focus of this group is now shifting towards the lower stratosphere and the upper troposphere, as part of new NASA initiatives to understand the effects of commercial aircraft on this chemically complex region of the atmosphere.

- Long-Term Monitoring of Ozone

Analysis of data from the Backscatter Ultraviolet (BUV) instrument series, begun in 1970, continues to be an active area of research within the Laboratory. The original BUV instrument and its follow-on instruments, Solar BUV (SBUV/SSBUV) and TOMS, played a major role in monitoring anthropogenic effects on ozone. The ozone group works actively with NOAA in producing high quality ozone data from the SBUV/2 instruments on the NOAA polar orbiters. The RCDF previously described is responsible for pre-launch calibration of these instruments. In addition to satellite monitoring, ground-based and aircraft lidar measurements of ozone and other trace gases are being made a part of the Network for Detection of Stratospheric Change.

- Atmospheric Effects of Aviation Project (AEAP)

The Atmospheric Chemistry and Dynamics Branch contains the Project Office of the AEAP which sponsors research to evaluate the impact of the current fleet of subsonic and proposed high-speed civil aircraft on stratospheric and tropospheric ozone and climate. AEAP is a project of the Office of Aeronautics at NASA HQ, run in coordination with observational and theoretical Programs in MTPE. Elements of this program include aircraft campaigns and modeling of photochemistry and transport, and of cloud-radiation interactions. Aircraft campaigns in 1996 included SUbsonic aircraft: Contrails and Cloud Effects Special Study (SUCCESS) (with the DC-8), directed at studying cloud-contrail-cirrus interactions, and partial support for Stratospheric Transport of Atmospheric Tracers (STRAT) (with the ER-2) directed towards understanding transport between different regions of the atmosphere. The Global Modeling Initiative is a multi-institutional effort that is assembling various contributed software modules to create a coupled chemical-transport model, with a shared code resident at Lawrence Livermore National Laboratory.

Rain Measurement Validation for TRMM

The TRMM GVP objective is to provide reliable area/time averaged rainfall data from numerous representative tropical and sub-tropical sites world-wide for comparison with TRMM satellite measurements. Rainfall measurements are made at Ground Validation (GV) sites equipped with weather radar, raingauges, and disdrometers. A range of data products derived from measurements obtained at GV sites will be available at the TRMM Science Data and Information System (TSDIS). The list of products has been developed to cover a range of space and time scales that will adequately reflect the rainfall variability and sampling characteristics of the TRMM Observatory. With these products, the validity of TRMM measurements will be established with accuracies meeting mission requirements.

During the pre-mission phase, the emphasis will be on rain measurement research, precipitation physics, development of measurement and procedural techniques for calibrating the mission GV sites, development of algorithms and software for generation of standardized products, provision of operational software to TSDIS, and establishment of procedures to assure a reliable flow of data and products to the TRMM Science Team. Long term, climatological rainfall data bases are also being collected and analyzed for each site. Field campaigns during the flight phase will also be an important element of the validation process.

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4.3 Data Analysis

Climate Analysis

Climate analysis seeks to identify natural variability on seasonal, inter-annual, and inter-decadal time scales, and to isolate the natural variability from the anthropogenic global change signal. Climate diagnostic studies use a combination of remote sensing data, historical climate data, model outputs and assimilated data. The most often used datasets include radiation data from the Earth Radiation Budget Experiment (ERBE), the International Satellite Cloud Climatology Project (ISCCP), the Outgoing Longwave Radiation (OLR) from Advanced Very High Resolution Radiometer (AVHRR), and the water vapor from TOVS; and rainfall data from the Global Precipitation Climatology Project (GPCP), the Comprehensive Ocean Atmospheric Data Set (COADS), the Tropical Ocean Atmosphere (TOA)-Array, and the assimilated data products from the DAO and others. Studies are also conducted to unravel the physics of ENSO, quasi- biennial oscillation, intraseasonal oscillation, and monsoon variability as well as water vapor and cloud feedback processes. Advanced analysis techniques including multivariate singular value decomposition, wavelets, and fractal characterization are used.

Rain Estimation Techniques from Satellites

A number of techniques have been developed to extract rainfall information, a key element in the study of the hydrologic cycle, from current spaceborne sensor data (Special Sensor Microwave/Imager [SSM/I]) and for potential use with data from future space missions (TRMM, EOS/Advaned Microwave Scanning Radiometer [AMSR]). The retrieval techniques belong to four categories: 1) physical/empirical relationships which exist between polar-orbit SSM/I measurements and rain rates; 2) a theoretical, multifrequency technique which relates the complete set of microwave brightness temperatures to rainfall rate at the surface; 3) an empirical relationship which exists between cloud thickness and rain rates, using TOVS sounding retrievals; and 4) an analysis technique which uses low-orbit microwave, geosynchronous infrared and raingauge information to provide a merged, global precipitation analysis.

The multifrequency technique (category 2) also provides information on the vertical structure of hydrometeors and latent heating through the use of a cloud ensemble model. The approach has recently been extended to combine spaceborne radar data with passive microwave observations. Scientists involved in rainfall algorithm development participate in international rainfall intercomparison studies such as the recent third Precipitation Intercomparison Project (PIP-3) involving satellite-based global rainfall maps and precipitation fields calculated from global models.

Aerosols/Cloud Climate Interactions

Theoretical and observational studies are being carried out to analyze the optical properties of aerosols and their effectiveness as cloud condensation nuclei for producing different drop size distributions in clouds, which in turn will affect the radiative balance of the atmosphere. Algorithms are being developed for routine derivation of aerosol loading optical properties and total precipitable water vapor from the future EOS-Moderate Resolution Imaging Spectrometer (MODIS) data. These algorithms are based on Airborne Visible/Infrared Imaging Spectrometer (AVIRIS), MODIS simulator, AVHRR and Landsat Thematic Mapper (TM) data. Laboratory scientists are actively involved in the analysis of data recently obtained from national and international campaigns of Smoke, Clouds And Radiation-Brazil (SCAR-B), SUCCESS, and Tropospheric Aerosol Radiative Forcing Observational eXperiment (TARFOX). Preliminary results show distinct differences in aerosol characteristics between SCAR-B (biomass burning) and TARFOX (industrial pollution) data. In SCAR-B, diurnal variation in particle concentrations and lognormal size distributions were clearly observed, which was not the case for TARFOX. However, aerosols from both sources serve as cloud condensation nuclei. In SUCCESS, small ice particles formed by jet exhaust frequently remained airborne for a long period of time. Microphysical properties of cirrus clouds observed in contrails differ from those of cirrus observed away from contrails. In turn, their optical and radiative properties were quite different. Extensive studies to assess the climatic impact by the direct and indirect effects of aerosols are underway.

Hydrologic Processes and Radiation Studies

Methods are being developed for the estimation of the atmospheric water and energy budgets, including calculating the radiative effects of absorption, emission and scattering by clouds, water vapor, aerosols, CO_2, and other trace gases. Both observational and modeling approaches are applied to study the interaction of clouds, water vapor, and radiation, and the effect on climate. The observational data include the ERBE radiation budgets, ISCCP clouds, Geostationary Meteorological Satellite (Japan) radiances, NCEP sea surface temperature, as well as Tropical Ocean Global Atmosphere Coupled Ocean Atmosphere Response Experiment (TOGA-COARE) observations, whereas the models include the GEOS GCM and the Goddard Cloud Ensemble model (GCE). The response of radiation budgets to changes in water vapor and clouds are studied during El Niño events in the Pacific basin and during westerly wind-burst episodes in the western tropical Pacific warm pool. The relative importance of large-scale dynamics and local thermodynamics on clouds and radiation budgets and modulating sea surface temperature are investigated.

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4.4 Modeling

Cloud and Mesoscale Modeling

There are two models in this area: a cloud-resolving model (GCE) and a regional/mesoscale model (Penn State/National Center for Atmospheric Research [NCAR] Mesoscale Model Version 5 [MM5]). These models are used for:

1) Classical meteorological applications such as the study of the dynamic and thermodynamic processes associated with frontal rainbands, surface (ocean, land, and soil) effects on atmospheric convection, cloud-chemistry interactions, tropical and midlatitude convective systems, stratospheric-tropospheric interaction, and of the effects of assimilating satellite derived water vapor and precipitation fields on tropical and extra-tropical regional-scale weather simulations.

2) Climate applications involving long-term integrations. These allow the study of air-sea interactions and their application to the cloud-climate feedback mechanisms; and surface energy, radiation, diabatic heating and water budgets associated with the weather systems studied during TOGA-COARE (i.e., Westerly Wind Bursts and super cloud clusters).

3) Applications for retrieval algorithms. The GCE model is providing the TRMM investigators with four dimensional data sets (hydrometeors/latent heating) for the development and improvement of TRMM rainfall and heating retrieval algorithms.

Physical Parameterization in Atmospheric General Circulation Models

The development of physical parameterization and sub-models of the physical climate system is an integral part of climate modeling activities. Laboratory scientists are actively involved in the development and improvement of physical parameterizations in two major areas: radiative transfer and moisture processes in the atmosphere. Both areas are extremely important for better understanding of the global water and energy cycles. For atmospheric radiation, efficient, accurate and modular longwave and shortwave radiation codes are being developed. The radiation codes allow the efficient computation of climate sensitivities to water vapor, cloud microphysics and optical properties and global warming potentials of carbon dioxide and various trace gases. For atmospheric hydrologic processes, a new prognostic cloud liquid water scheme is being developed which includes representation of source and sink terms as well as horizontal and vertical advection. This scheme incorporates attributes from physically based cloud life cycles including the effects of downdraft; full cloud-microphysics within convective towers and anvils, cloud-radiation interactions, cloud microphysics; and cloud inhomogeneity correction. Both the radiation and the prognostic water scheme are being tested with *in situ* observations from Atmospheric Radiation Measurement (ARM) and TOGA-COARE. The radiation schemes are being incorporated into the latest version of the GEOS model and the GCE model.

Trace Gas Modeling

In addition to long-term monitoring, a comprehensive research program is underway to understand the chemical and dynamical processes that govern the formation and destruction of ozone. The overall goal of the trace gas modeling program is to understand the trends in ozone and other trace gases, and to predict future changes in the ozone layer as a result of natural and anthropogenic influences. The trace gas modeling effort has four components: (1) Lagrangian models: These chemical models are closely coupled to the trajectory models of an air parcel. The Lagrangian modeling effort is primarily used to interpret aircraft and satellite chemical observations. (2) Two-dimensional (2D) non-interactive models: These latitude-height models have comprehensive chemistry but use specified, parameterized dynamics. They are used both in data analysis and multidecadal chemical assessment studies. (3) Two-dimensional interactive models: These 2D models have interactive radiation and dynamics and can study the dynamical impact of major chemical changes. (4) Three dimensional (3D) models: These models have a full chemistry package and use the analyzed wind fields for transport. The 3D models are used to interpret observations, assess the impact of aircraft pollution, and determine the accuracy of the two dimensional models.

Trace gas data from sensors on the Upper Atmosphere Research Satellite (UARS) and from various NASA sponsored aircraft and ground based campaigns are used in rigorous testing of the models. The integrated effects of processes such as stratosphere troposphere exchange, not resolved in 2D and 3D models, are critical to the reliability of these models. Trace gas simulations in 3D models using winds and temperature from GEOS DAS provide a test of the consistency of the meteorological fields with the trace gas observations and the photochemical model, which is an important step towards constituent assimilation.

Coupled Atmosphere-Ocean-Land Models

To study climate variability and sensitivity, it is necessary to couple the atmospheric GCMs to ocean and land-surface models. Much of the work in this area is conducted in collaboration with the Laboratory for Hydrospheric Processes. The ocean models predict the global ocean circulation--including the Sea Surface Temperature (SST)--when forced with atmospheric heat fluxes and wind stresses at the sea surface. Land-surface models are detailed representations of the primary hydrological processes, including evaporation, transpiration through plants, infiltration, runoff, snow and ice accumulation sublimation and melt, and groundwater budgets.

Coupled ocean-atmosphere models are used to study inter-annual to inter-decadal time scales, with emphasis on phenomena such as the ENSO. Atmosphere-land coupled models are used to study the physical mechanisms responsible for the maintenance of the global hydrologic cycle and the role of land-surface processes in interannual climate variability. Climate experiments have been carried out with atmosphere-land models on monsoon simulations, deforestation experiments, atmospheric teleconnections, effects of radiation on large scale dynamics, and the interaction of soil moisture and precipitation.

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4.5 Spaceflight Missions

Spaceflight missions are central to NASA's ability to carry out its science programs. Global change studies require a comprehensive set of observations from existing and planned missions. Likewise, planetary sciences will rely on instruments such as gas chromatographs and mass spectrometers to study the atmospheres of planets. A number of research missions are planned for the 90's and beyond to meet these goals.

Members of the Laboratory are Project and Deputy Project Scientists for the following missions (launch dates shown in parenthesis):

1) UARS

To understand the chemistry and dynamics of the stratosphere and mesosphere. (1991)

2) TOMS Missions

To provide daily mapping and long-term trend determination of total ozone and to obtain information on tropospheric ozone, dust, and aerosols. (1996)

3) TRMM

To understand global energy and water cycles by providing distributions of climatological rainfall and inferred heating over the tropics. (1997)

4) EOS AM

To study the terrestrial and oceanic surfaces, clouds, radiation, and aerosols. (1998)

5) EOS/CHEM

To understand the atmospheric chemical species and their transformations. (2002)

Principal Investigators for the following instruments are members of the Laboratory:

1) TOMS on Earth Probe and Advanced Earth Observing System (ADEOS) Missions

úTo provide daily mapping and long-term trend determination of total ozone. (1996)

2) IR Spectrometer Imaging Radiometer (ISIR)

To improve infrared observations of clouds and the surface from the Space Shuttle with greater coverage and temporal sampling in combination with microwave and active optical sensing. It is based on smaller and more reliable infrared imaging using uncooled array detectors. (1997)

3) Huygens Probe: GCMS

To determine the chemical composition of gases and aerosols in the atmosphere of Titan . (1997)

4) Cassini: INMS

To determine the chemical composition of positive and negative ions and neutrals in the inner magnetosphere of Saturn and in the vicinity of the icy satellites. (1997)

5) Planet-B: Neutral Mass Spectrometer

To measure the composition of the neutral atmosphere of Mars to improve knowledge and understanding of energetics, dynamics and evolution of the atmosphere. The mass spectrometer will be flown on a spacecraft developed by the Institute of Space and Astronautical Science, Japan. (1998)

6) Shuttle Ozone Limb Sounding Experiment (SOLSE)/Limb Ozone Retrieval Experiment (LORE)

An experimental payload designed to demonstrate the measurement of the vertical distribution of ozone from the upper stratosphere to the lower troposphere. SOLSE is a photometer which uses a Charge Couple Device (CCD) detector to measure the mid to upper stratosphere limb; LORE is an imaging spectrometer which uses three filters and linear arrays to measure the lower troposphere limb. The first flight experiment is aboard STS 87. (1997)

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4.6 Aircraft, Balloon, and Ground Based Instruments

The experimental programs of the Laboratory involve laboratory, field and space experiments using *in situ* and remote sensing instruments. Instrument systems are conceived, designed and developed for flight on rockets, balloons, and aircraft and for ground based observations. These systems are outlined according to the scientific disciplines they serve (Figure 2). The use of balloon and airborne platforms provides a view of processes such as precipitation and cloud systems from high in the atmosphere. Such platforms serve as a step in the development of space borne instruments. For some instruments, such as the Cloud Lidar and the lidar for measuring winds, plans are underway to propose them for space missions.

Instrument Research and Development Programs				
	Atmospheric Structure and Dynamics	**Atmospheric Chemistry**	**Clouds and Radiation**	**Planetary Atmospheres/ Solar Influences**
Space		Shuttle Ozone Limb Sounding Experiment (SOLSE) Raleigh Scattering Attitude Sensor (RSAS) Limb Ozone Retrieval System (LORE) (Shuttle)	IR Spectrometer Imaging Radiometer (ISIR) (Shuttle)	Solar EUV Flux Monitor Galileo Probe Mass Spectrometer Cassini Gas Chromatograph Mass Spectrometer (GCMS) Cassini Ion Neutral Mass Spectrometer (INMS) Planet B Mass Spectrometer Rosetta Rendezvous and Lander Mass Spectrometer
Aircraft	Large Aperture Scanning Airborne Lidar (LASAL) Holographic Scanner for Lidar ER-2 Doppler Radar (EDOP)	Methane Raman Lidar (DC-8)	Visible and IR Lidar (VIRL)(DC-8) Cloud Lidar System (CLS)(ER-2) Visible and IR Cloud Radiometer (ER-2) Tilt Scan CCD Camera (ER-2)	Solar Disc Sextant(Balloon)
Ground	Water Vapor Raman Lidar Holographic Circle to Line Converter for Lidar Direct Detection Wind Lidar (Edge Technique)	Ozone Lidar Temperature and Aerosol Lidar Tropospheric Ozone Lidar	Micro-Pulse Lidar	

Figure 2

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All instrument systems provide information leading to basic understanding of relations between atmospheric systems and processes, and/or serve as calibration references for satellite instrument validation. Principal instruments and their objectives are:

Aircraft Instruments

1) Cloud Lidar System (CLS)

Measures cloud and aerosol structure from the high altitude ER-2 aircraft for combined integration of multispectral visible, microwave, and infrared imaging radiometers. The data are used in radiation and remote sensing studies.

2) Tilt Scan CCD Camera (TSCC)

Measures bi-directional reflectance of high and low clouds used in cloud radiative transfer studies and remote sensing applications.

3) ER-2 Doppler Radar (EDOP)

Measures vertical rain and wind structure of precipitation systems to improve understanding of mesoscale convective system structure and spaceborne rain measurement algorithm validation.

4) Large Aperture Scanning Airborne Lidar (LASAL)

Measures atmospheric backscatter with emphasis on boundary layer height and structure. Capable of (raster) scanning at up to 90 degrees per second and providing three-dimensional aerosol structure of the lower troposphere and boundary layer.

5) Airborne Raman Lidar (ARL)

Measures the structure and concentration of methane in the troposphere and lower stratosphere to contribute to understanding the chemistry of this region.

Balloon Instrument

Solar Disk Sextant (SDS)

Measures the diameter of the Sun to milli-arc second accuracy to determine the relation between the diameter and the solar constant.

Ground Based Instruments

1) Raman Lidar

Measures light scattered by water vapor, nitrogen, oxygen, and aerosols to determine the water vapor mixing ratio, aerosol backscattering, and aerosol extinction and their structure in the troposphere. These trailer-based measurements are important for studies of radiative transfer, convection, and the hydrological cycle, as well as for assessing the water and aerosol measurement capabilities of surface, aircraft, and satellite-based instruments.

2) Doppler Lidar

Measures winds in the planetary boundary layer, using the Edge Technique. It is expected to be extended to the full troposphere in 1997.

3) Micro Pulse Lidar (MPL)

Makes quantitative measurements of clouds and aerosols. It is a unique "eye-safe" lidar system that operates continuously 24 hours a day in an autonomous fashion,

4) Stratosphere Ozone Lidar Trailer Experiment (STROZ LITE)

Measures the structure and concentration of ozone.

5) TRMM Validation

Doppler and polarimetric radars, supported by specifically developed disdrometers and rainrate gauges are the fundamental components of the TRMM Validation effort.

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4.7 EOS Interdisciplinary Investigations

The overall goal of the EOS Program is to determine the extent, causes, and regional consequences of global climate change. This major scientific challenge will be addressed by more than 20 instruments flown on a series of spacecraft for a period of at least 15 years. In addition to the scientific investigations to be carried out by the instrument scientists, the EOS program also supports various interdisciplinary science investigations. The latter investigations are to improve understanding of the Earth as a system by developing and refining integrated models which will use observations from EOS instruments. The Laboratory is carrying out the following two interdisciplinary science investigations:

1) Global Hydrologic Processes and Climate

The goal is to provide a description and a better understanding of the global hydrologic and energy cycle. The investigation focuses on three scientific objectives aimed at improving understanding of the following: the physical mechanisms of atmospheric hydrologic processes; the role of hydrologic processes in large-scale ocean, atmosphere, and land interactions; and the role of land surface processes in the global hydrologic cycle.

2) Stratospheric Chemistry and Dynamics

The goal is to separate natural from anthropogenic changes in the Earth's atmosphere, to determine their effects on ozone, and to assess radiative and dynamical feedbacks. This will be done by analysis of stratospheric chemical and dynamical observations from EOS instruments and current satellites and aircraft campaigns. This includes a study [1] concerning the processes which produce the Antarctic ozone hole and the interannual differences in the amount of ozone lost. The study combines UARS data, trajectory modeling, and TOMS observations. Reports from this investigation can be found on the World-Wide Web (http://hyperion.gsfc.nasa.gov/EOS/EOS.html).

1. "Development of the Antarctic Ozone Hole," M. R. Schoeberl, A. R. Douglass, S. R. Kawa, A. E. Dessler, P. A. Newman, R. S. Stolarski, A. E. Roche, J. W. Waters, and J. M. Russell, *J. Geophys. Res.-Atmos.*, **101**, 20909-20924, 1996.

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4.8 Support for NOAA Operational Satellites

Goddard supports NOAA remote sensing requirements. Laboratory Project Scientists support the NOAA Polar Orbiting Environmental Satellites (POES), also referred to as Meteorological Satellites (METSAT), and the Geostationary Operational Environmental Satellite (GOES) Project Offices. Project Scientists assure scientific integrity throughout mission definition, design, development, operations and data analysis phases for each series of NOAA platforms. Laboratory scientists also support the NOAA SBUV/2 ozone measurement program which is now operational within NOAA/National Environmental Satellite Data and Information Service (NESDIS), with a series of SBUV/2 instruments flying on POES/METSAT. Post-doctoral scientists work with the Project Scientists to support development of new and improved instrumentation and to perform research using NOAA's operational data.

GOES

NASA GSFC project engineering and scientific personnel support NOAA for the GOES-I/M satellites for the periods 1994-2004. GOES supplies images and soundings to study atmospheric processes, such as haze, winds, clouds and surface conditions. In particular, GOES observations are used by climate analysts to monitor the diurnal variability of clouds and rainfall, and to track the movement of water vapor in the upper troposphere, where it is otherwise unobservable. In addition to high quality imagery, the new GOES satellites also carry an infrared multichannel radiometer that NOAA uses to make hourly soundings of atmospheric temperature and moisture profiles over the United States. These mesoscale soundings are expected to improve NOAA's numerical weather forecasts of local weather by the late 1990's. Meanwhile, the GOES Project Scientist at GSFC provides free public access to real-time weather images for regions all over the western hemisphere via the World-Wide Web (http://climate.gsfc.nasa.gov/).

POES

Algorithms are being developed and optimized for analysis of data from HIRS-3 and the Advanced Microwave Sounding Unit (AMSU) when launched on NOAA K in 1997. Simulated data for the Atmospheric Infrared Sounder (AIRS) is being analyzed to assess its utility for the next operational meteorological sounding system on NOAA N' in 2007 and the NOAA/DOD/NASA converged platform in 2010. The applicability of the Interferometer Temperature Sounder (ITS), another proposed advanced infrared sounder, is being assessed for potential use as the future operational infrared sounder.

SBUV/2

NASA's responsibility is to monitor the pre-launch and post-launch calibration of the SBUV/2 and to develop new algorithms to process ozone more accurately. Laboratory scientists recently developed an algorithm that was used to reprocess the NOAA 11 SBUV/2 data record, covering the period from January 1989 to the present. The algorithm is designed to increase the accuracy of ozone measurements in the Antarctic ozone hole. The absolute calibration was set through comparison with SSBUV, while the relative calibration was stabilized through January 1993 to within ± 2-5% per decade. This SBUV/2 data set was joined with the NASA SBUV record to produce a continuous 15 year record of ozone. The resulting trends were reported in the 1994 WMO United Nations Environment Program (UNEP) report.

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